1) linear with E vector vertical
2) linear with E vector horizontal
3) circularly polarized,

given that the microwave horn receiver operates in the TE_{10} mode (E vector parallel to short sides of horn).

The report should contain:

1) A comparison of the relative gains of each antenna.
2) The variation in gain of the discone antenna over its 360° pattern.
3) The increase in directivity of the halfwave dipole when a director and reflector are added; also, the change in its front to back ratio.
4) A simple sketch on how the electric field vector makes a smooth transition from the antenna elements to free space for each antenna. The measured radiation polarizations are used as a guide.

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Oliver Heaviside (1850-1925)*

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Summary—**90 years ago, in 1873, Maxwell (1831–1879) published his "Treatise On Electricity and Magnetism." The aim of this paper is to review the life and the scientific contributions of one of the first and the most ardent and loyal of his disciples, one of the most brilliant applied mathematicians and scientists of all time, the first modern electrical and electronics engineer, a self-taught man who, more than any other single man, was instrumental in developing the electromagnetic field theory and its classical applications into the form in which it is taught today in our colleges and universities—Oliver Heaviside.**

I. BIOGRAPHY

OLIVER HEAVISIDE may probably be classified best as an outstanding applied mathematician. He was truly a pioneer in this new branch of science, and like the revolutionary in any field, he was attacked strongly for his view on the "experimental nature" of mathematics as a tool. Yet, his contributions to mathematical analysis are taught today as standard methods in applied physics and in electrical engineering curricula all over the world.

Oliver Heaviside was born in London, England, on May 13, 1850, and he received, apparently, the usual public school education. His first electrical paper appeared on July 5, 1872, and dealt with a bridge method for comparing electromotive forces. After leaving school Heaviside was employed by the Great Northern Telegraph Company at Newcastle-on-Tyne as an operator of submarine cables until sometime in 1874. He presumably left this position because of increasing deafness and moved to Paignton, near Torquy, on the southern coast of England, where he lived in very modest circumstances. Undoubtedly, he wanted to devote all his time to the study of Professor Maxwell's "Treatise On Electricity and Magnetism" which had just been published. Heaviside admired Maxwell and his theory greatly, and with remarkable analytic deftness, utilized this theory in innumerable detailed applications.

In his first papers on the theory of telegraphy, published during 1874–1881, he still followed the established lines of Professor W. Thomson (Lord Kelvin, 1824–1907), wherein he considered transient and steady-state conditions on the basis of diffusion theory, disregarding the effects of the inductance. Heaviside had already displayed complete familiarity with Fourier (1768–1830) series expansion and with functional systems like Legendre polynomials and Bessel (1784–1864) functions. In all probability, he acquired this mathematical foundation by studying on his own. At the death of Maxwell in 1879, Heaviside asserted himself as a vigorous and aggressive disciple of Maxwell and became the champion of his theory, which was then still

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speculative because no experimental evidence of wave propagation had been given.

In his next paper, "On Induction Between Parallel Wires," published in 1881, Heaviside sharply differentiated between static and electromagnetic induction and demonstrated mathematically the existence of "traveling waves" along parallel wires when both types of electrical induction exist simultaneously. This laid the foundation for his later complete development of transmission line theory and, in particular, the concept of "distortionless" transmission, first advanced by him in 1887.

From 1882 until 1887 Heaviside published a series of articles in which he formulated the vector analysis representation of Maxwell's equations and defined the concept of the energy-flow vector (June, 1884). The latter was deduced practically at the same time by Professor Poynting and subsequently designated as Poynting vector! Heaviside gave a detailed account of Maxwell's theory of the electromagnetic field in vector notation and used it for many applications which since then have became classical. He gave a formal exposition of operational methods, applying them to circuits and fields, and he also studied propagation of electromagnetic waves along parallel wires and coaxial cables. Heaviside was requested by the editor of the *Electrician*, where he published, to discontinue his series of articles as of November 30, 1887. This was probably a result of Heaviside's disagreement with Sir W. H. Preece, head of the British Telegraph and Telephone System, who accepted the view that the inductance should be neglected in (transatlantic) cable telegraphy.

At this time Professor Hertz (1857–1894) succeeded in generating very short waves and demonstrated, in his now famous experiments (1886–1888), the existence of displacement current and the reflection, refraction and linear polarization of the electromagnetic waves produced by a spark oscillator, thus verifying experimentally the crucial point of Maxwell's theory. Many people started to read Heaviside's papers on Maxwell's theory and his articles were accepted again for publication by the *Electrician*. After publishing several additional papers on electromagnetic propagation and radiation from moving charges during 1888–1889, he was asked to resume his series of articles on Maxwell's theory.

The writings of Heaviside from 1891 to 1912, when he apparently ceased scientific work, are collected in the three volumes of "Electromagnetic Theory," which appeared in 1893, 1899 and 1912, respectively.

Heaviside was elected a Fellow of the Royal Society in 1891 at the age of 41.

In 1899 he was elected an Honorary Member of the American Academy of Arts and Science.

In 1908 he was elected an Honorary Member of the Institution of Electrical Engineers (IEE, London).

In 1918 he was elected an Honorary Member of the American Institute of Electrical Engineers (AIEE).

In 1921 he became the first recipient of the Faraday Medal of the Institution of Electrical Engineers (IEE, London).

Heaviside also received the honorary degree of Doctor of Philosophy from the University of Gottingen in Germany.

From 1874 on, Heaviside lived with at least a housekeeper in Paignton near Torquy in a house overlooking Tor Bay on the southern coast of England. He spent his last years in complete seclusion after his housekeeper was taken to an institution in about 1920. He was singularly proud and very sensitive; although he received a small government pension and lived in very modest circumstances all of his life, he seemed not to wish it any different. He died at Torquy on February 3, 1925.

II. Scientific Contributions

Heaviside's most important contributions were, in a broad sense, the rigorous mathematical analysis of physical problems and the development of direct mathematical methods for their solution. This at once characterizes him as a great applied mathematician whose influence upon theoretical electrical engineering has been most profound.

The following are some of his major specific contributions:

1) Heaviside developed the vector analysis and started to use it exclusively for Maxwell's equations in 1882. Together with Professor Gibbs (1839–1903), who developed the vector analysis independently at Yale University in 1881–1884, he had many bitter controversies with Professor Tait, who was the leading mathematician in support of the quaternion theory, developed originally by Professor Hamilton (1866).

2) Maxwell (1831–1879), in his treatise, used quaternions principally for the field quantities; he actually used comparatively little space for the general field equations and for solutions of wave problems, and his theory failed to impress many. Heaviside expounded Maxwell's theory in detail and in very clear, systematic terms, much in the same form as since has become classical.

3) Heaviside established the concept of the energy-flow vector independently of and in more detail than did Professor Poynting. He used vector notation for his proof, as we use it to-day, while Poynting used the quaternions. The energy-flow vector is known today as the Poynting vector.

4) Heaviside extended, in the proper manner, the field equations to the case of moving media (electrons) and advanced some of the first complete solutions (without relativity correction, which was added later by H. A. Lorentz).

5) He was the first to introduce the concept of magnetic currents and magnetic charges and to incorporate them as a part of the symmetric field equations.

6) He gave many specific solutions to the wave equation in the most important orthogonal coordinate systems.

7) Many authors preferred the more traditional use of potential functions. Heaviside always felt, as in numerous cases we do today, that direct use of the field vectors made the presentation clearer.

8) Lord Kelvin (William Thomson, 1824–1907) assumed the magnetic effects to be negligibly small in transmission line theory. He considered only the capacitance and the resistance per unit length and derived (1855) the well-known diffusion equation. Kirchhoff (1824–1887) extended the long line theory (1857) to include the effect of self-induction, and he deduced the finite velocity of propagation of light—but Kelvin's theory dominated the thinking of the scientists at that time. Heaviside contributed (against bitter opposition!) practically the entire transmission line theory as we know it today. He introduced the leakage as the fourth parameter, discussed traveling-wave solutions and discovered, theoretically, the distortionless transmission line.

9) Heaviside was the first one to suggest, on theoretical grounds, the increase of the inductance per unit length as the solution for the problamatic transatlantic cable.

10) Heaviside applied Maxwell's equations to the two-dimensional field problems associated with propagation along long wires. He stressed the guiding effect of the conductors and introduced the concept of "waveguides." He discussed in detail the issues involved in the transition from field concepts to circuit concepts.

11) Heaviside was the first one to coin the terms capacitance, inductance, leakance, resistivity, conductivity, permittivity, impedance, reactance, etc. Lord Rayleigh (1842–1919) stated, "Heaviside has given us not only the transmission line theory in its full generality, but also a ready-made terminology," which is now commonplace parlance with all electrical engineering students.

12) Heaviside first introduced operational methods, subsequently called Heaviside Operational Calculus. Only later authors discovered the relationship with Fourier (1768–1830) and Laplace (1749–1827) integrals. These operational methods are used widely today under the name of Laplace Transformation!

13) Heaviside was the first to study the propagation of transients.

14) He was the first to introduce the unit step function, which bears his name.

15) Heaviside was the first to suggest (1882) the rationalized system of units, in order to ger rid of the extra 4π in the field relationships. Even today, a system of units called the Heaviside-Lorentz system of units is used in physics. It remained for Giorgi (1901) to suggest the MKSQ system of units.

16) In Heaviside's writing one finds the first available reference to antennas or electrodes in an infinite medium.

17) Heaviside recorded (1902) his surmise of the ionosphere entirely independently of Professor Kennelly. It was subsequently called the Kennelly-Heaviside layer and, later, the ionosphere.

A detailed summary of Heaviside's scientific contributions may be found in a critical and historical introduction by Weber [4].

III. Discussion and Recommendations

It appears that Oliver Heaviside is not very well known to electrical engineering students and it is seldom mentioned in present-day classrooms. Most students are not aware of his name and his scientific contributions (unlike the names of Maxwell, Coulomb, Volta, Ampere, Ohm, Faraday, Gauss, etc.) and others vaguely associate his name with the unit step function, if at all. This lack of awareness is hardly compatible with the many outstanding contributions of this great scientist, the first modern electrical and electronics engineer. In the light of Heaviside's extensive scientific accomplishments, it is suggested that:

1) It be pointed out in classrooms and in textbooks that Gibbs and Heaviside were the first to use and develop the modern vector analysis notation and that Heaviside was the first to express Maxwell's field equations in terms of the modern vector notation.

2) The quantity presently known as the Poynting vector be renamed the Poynting-Heaviside vector (*P-H* vector), or alternatively, that the Poynting theorem of electromagnetic energy balance be renamed the Heaviside theorem.

3) Maxwell's equations for moving media for the nonrelativistic case be renamed the Maxwell-Heaviside equations.

4) The presently known "transmission line equations" be renamed the "Heaviside equations."

5) It be reemphasized in the classrooms and in textbooks that the first suggestion, on theoretical grounds, for the increase of the inductance in the transatlantic cable came from Heaviside.

6) The so called "Laplace Transform" be renamed the "Laplace-Heaviside Transform."

7) It re-emphasized that the rationalized system of units was first suggested by Heaviside.

It appears likely to the author that because of tradition, presently available texts, and other reasons, most of the above recommendations for bringing posterity to the name of Oliver Heaviside, in accordance with his outstanding scientific contributions, will not be accepted immediately, if at all. In order to focus the effort to effect changes at the present time, it is suggested that the immediate goals be:

1) To establish an "IEEE Committee for Heaviside" (IEEE-CFH), which will pursue and discuss the above suggestions and will coordinate the effort for the reestablishment of the name of Oliver Heaviside in electrical and electronic engineering.

2) To rename the presently nameless "transmission line equations,"

$$\partial V/\partial z = -L\partial I/\partial t - RI \tag{1a}$$

$$\partial I/\partial z = -C\partial V/\partial t - GV, \tag{1b}$$

THE HEAVISIDE EQUATIONS, in honor of Oliver Heaviside in recognition of his great scientific contributions to transmission line theory and electromagnetic field theory. This is a small enough tribute to pay this great scientist and engineer at the present time. The author will appreciate any reaction on the above suggestions from the membership, even in the form of a postcard.

ACKNOWLEDGMENT

All of Section I and most of Section II of this paper have been taken from "A Critical and Historical Introduction," by Ernst Weber, prefacing Dover Publications' edition of Oliver Heaviside, "Electromagnetic Theory" vol. I, II, and III, published in 1950, and it is published here with their permission. Certain changes have been introduced by the author in order to shorten or rearrange the material for the present paper. The author is very grateful to Dr. E. Weber, President, Polytechnic Institute of Brooklyn, N. Y., and the First President of the Institute of Electrical and Electronics Engineers, for his permission to use his material. This does not imply in any way his agreement or disagreement with the Discussion and Suggestions in Section III of this paper, which are the sole responsibility of the author of this article. The author would also like to thank several friends and associates in the Antenna Laboratory, The Ohio State University, Columbus, Ohio and in the Electrical Engineering Department, The University of Kansas, Lawrence, Kansas, for several discussions on the above subject.

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